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Office lighting for good visual task conditions

At present, most lighting installations are designed simply to give a specified average illuminance on a horizontal working plane, although sometimes predictions are made of the level of discomfort glare to check that it is within recommended limits. In many cases no other design work is done. To ensure good visual task conditions in the office it is important that other aspects of the lighting are considered. By doing so, a more efficient working environment will result with less likelihood of problems of visual distraction or fatigue and the potential for more efficient energy use.

Office lighting is designed primarily to enable visual tasks to be performed by the occupants; it should, therefore, be designed to make the task as visible as possible. Bright reflections in the task will reduce its visibility and may cause discomfort. This digest considers the causes of these reflections for common office tasks such as written and printed material on paper and visual display units associated with word processors and other computer operations. The use of Contrast Rendering Factor (CRF) to quantify the effect of reflections is explained and guidance is given on acceptable levels of CRF and methods of calculation and measurement. Suggestions on design to avoid veiling reflections in offices are made.

The human eye sees the details of a visual task by discriminating between the darker and lighter parts of it. For example, this printing is visible because the letters are considerably darker than the paper on which they are printed. This difference in brightness of the visual task (the task contrast) can be expressed quantitatively as:

$$C = \frac{L_b - L_t}{L_b}$$

where L_b = luminance (brightness) of background and
L_t = luminance (brightness) of task.

In general, high contrast visual tasks are easier to see than those with lower contrast.

The contrast of a visual task depends on the intrinsic reflectance properties of the task and on the way in which it is lit. If the task material is completely matt, incident light is reflected equally in all directions, therefore the direction of incident light is unimportant. However, very few visual tasks are composed of materials which are truly matt and if

Terms used in this digest:

Visual task:	Conventionally, those details and objects that must be seen for the performance of a given activity, including the immediate background of the details or objects.
Task contrast:	The difference in brightness between the detail and the background of the visual task divided by the brightness of the background. In general, the higher the contrast, the greater the task's visibility.
Veiling reflection:	A bright defocussed image reflected in the visual task; for example an image of luminaire or a window. The effect usually is to reduce the task contrast and hence its visibility.

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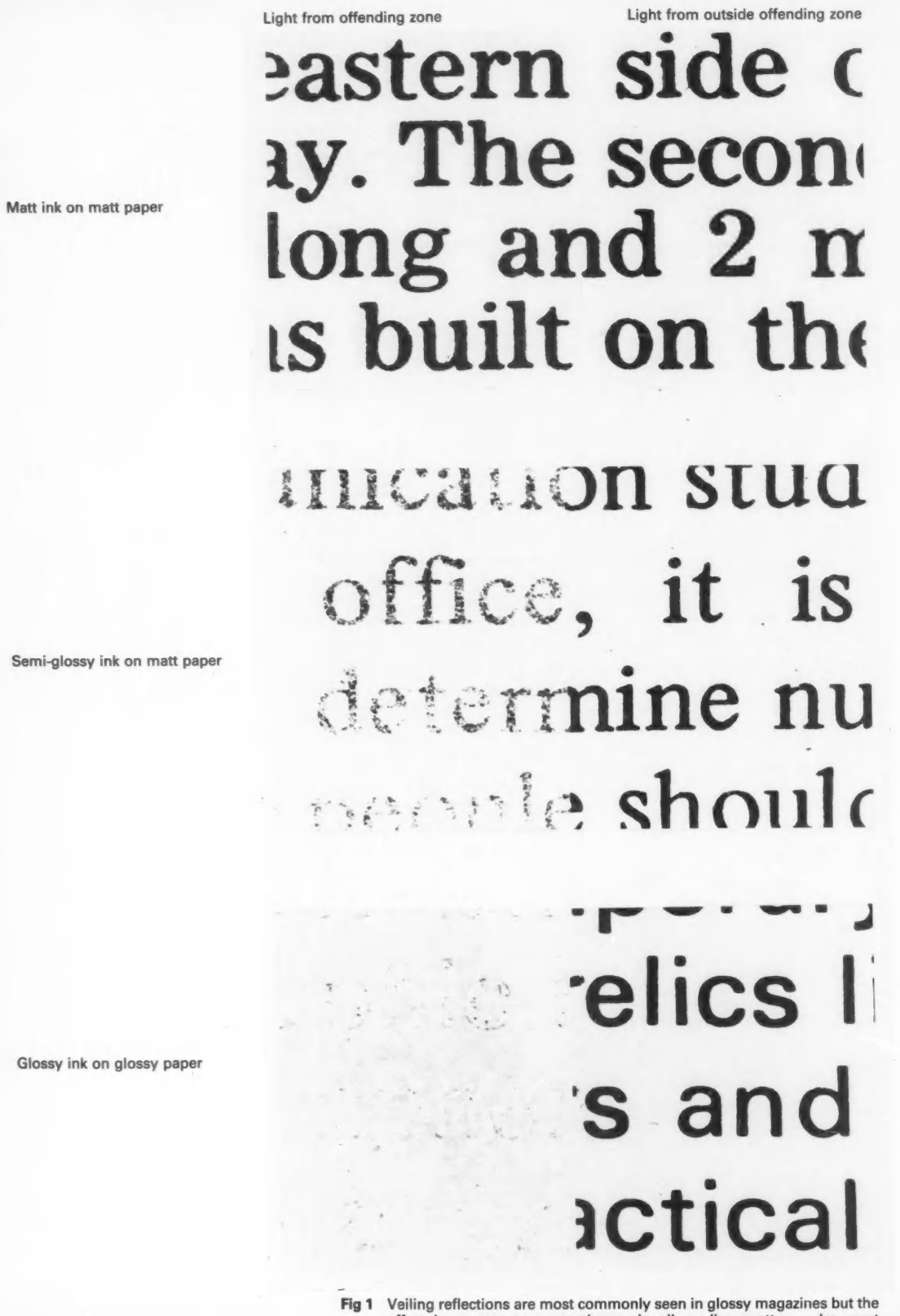

Fig 1 Veiling reflections are most commonly seen in glossy magazines but the effect is present to some degree in all reading matter under most conventional lighting installations.

the surfaces of these materials produce a specular, or mirror-like, component of reflection, defocussed images of bright sources such as luminaires are seen reflected in them. These bright images produce a veiling effect reducing the task contrast and hence its visibility (see Fig 1). The incident light direction is therefore crucial to the observed task contrast. This is most apparent with very glossy materials but can also be demonstrated to some extent using this Digest, with the page lit from the front at an angle of incidence equal to the viewing angle (see Fig 2).

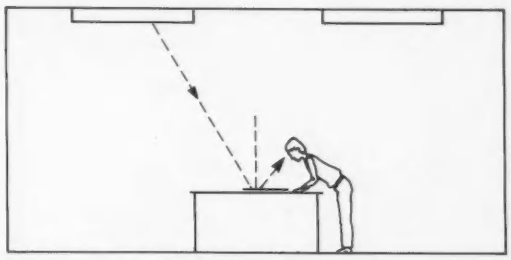

Fig 2 Viewing situation: angle of incidence = angle of reflection.

For a visual task with specular materials occupying a certain area (eg a page on a desk) there will be a set of incident directions from which the light will produce an image of the light source on some part of the task area. These incident directions can be projected on to the ceiling, where they form an area called the 'offending zone'. Any bright luminaires situated within the offending zone produce mirror-like 'veiling reflections' in the task. As about 85 per cent of horizontal office tasks are viewed at angles between 0° and 40° to the vertical, these angles have been used to produce the offending zone shown in Figure 3. A simple way to find the offending zone for a particular situation is to replace the task with a mirror of the same size: the area of the room surface seen in the mirror from the viewing position comprises the offending zone.

Contrast Rendering Factor

Visual tasks with materials of different specularity show different contrast variations as the direction of light falling on the task changes. For example, a glossy visual task may have a high contrast at one position and a low contrast due to veiling reflections at another position, while a matt visual task may have the same medium contrast at both places. A given value of visual task contrast therefore gives insufficient information about the effects of the lighting. To reduce this ambiguity, the contrast of the task can be measured under a reference condition of completely diffuse unpolarised incident light. The ratio of the visual task contrast under the lighting being studied to its contrast under reference lighting – the Contrast Rendering Factor (CRF) – is a relative measure of the ability of the lighting to produce high contrast and hence good visibility. If, in the example above, at a particular point in a room a glossy visual task has a high contrast and a matt visual task has a medium contrast and under reference lighting the glossy visual task again has a high contrast and the matt visual task has a medium contrast, the CRF is high at that point in the room for both tasks. But if at another point the glossy visual task has a low contrast, its CRF is also low at that point indicating poor visibility.

The reference lighting condition is chosen because it is relatively easy to reproduce, not because it gives the highest possible contrast for the visual task. Hence CRF may have values greater or less than unity depending whether the lighting being studied produces a visual task contrast better or worse than the reference lighting. In general, a high CRF indicates good visual task conditions which will allow good task performance.

The effect of illuminance

The human visual system becomes more sensitive to small differences in brightness (ie contrast) as the overall brightness increases and so visual tasks with contrasts usually encountered in offices become more visible at higher luminances. However, at the illuminances commonly used, this increase in visibility because of increased illuminance is relatively small for most tasks. Greater increases in visibility can be produced by increasing the visual task contrast. One way of doing this is to increase the CRF at a fixed illuminance. In principle, if CRF is increased, the same visibility can be obtained at a lower illuminance, enabling a reduction in energy consumption. However, insufficient is known about the detailed relationship between visibility and performance of visual tasks to enable the trade-off to be performed and further research is being carried out to provide design guidance.

Visual Comfort

Veiling reflections not only affect task performance by reducing the contrast of visual tasks, they also give rise to feelings of discomfort and increased task difficulty. Indeed, veiling reflections have been shown to produce discomfort before they are bad enough to cause a measurable decrease in task performance. A high CRF should therefore be sought for comfortable working conditions.

Recommended level of CRF for offices

Although the complete avoidance of veiling reflections will lead to good task visibility and comfortable working conditions, this is not usually possible. It is therefore necessary to know to what extent some veiling reflections can occur before either task performance decreases appreciably or discomfort causes complaints, ie the minimum acceptable value of CRF.

Lighting recommendations in Great Britain are mainly taken from the IES Code for Interior Lighting published by the Illuminating Engineering Society (now the Lighting Division of the Chartered Institution of Building Services). The 1977 edition of the Code advocates the avoidance of veiling reflections but gives no guide as to what may be acceptable. A more recent publication, the Illuminating Engineering Society of North America's Lighting Handbook 1981, gives only similar general recommendations.

However, research has shown that for office tasks discomfort occurs as CRF decreases before there is any appreciable performance drop. Comfort is therefore the more critical design factor. Prolonged discomfort may also lead to long-term performance loss, although this has yet to be demonstrated. Studies of the acceptability of veiling reflections have shown that, regardless of initial visual task contrast, weak veiling reflections are subjectively unimportant for written tasks on matt or semi-matt paper and it has been recommended that a CRF of 0.7 should be used as a standard for offices. For illustrations and very glossy paper, CRF does not seem to be a suitable measure for predicting subjective responses to specular reflections since contrast reversal may occur (where task detail becomes brighter than the background), producing high contrast but considerable discomfort owing to veiling reflections. Even so, situations where CRF is high for the more matt tasks will tend to give good visual conditions for glossy tasks.

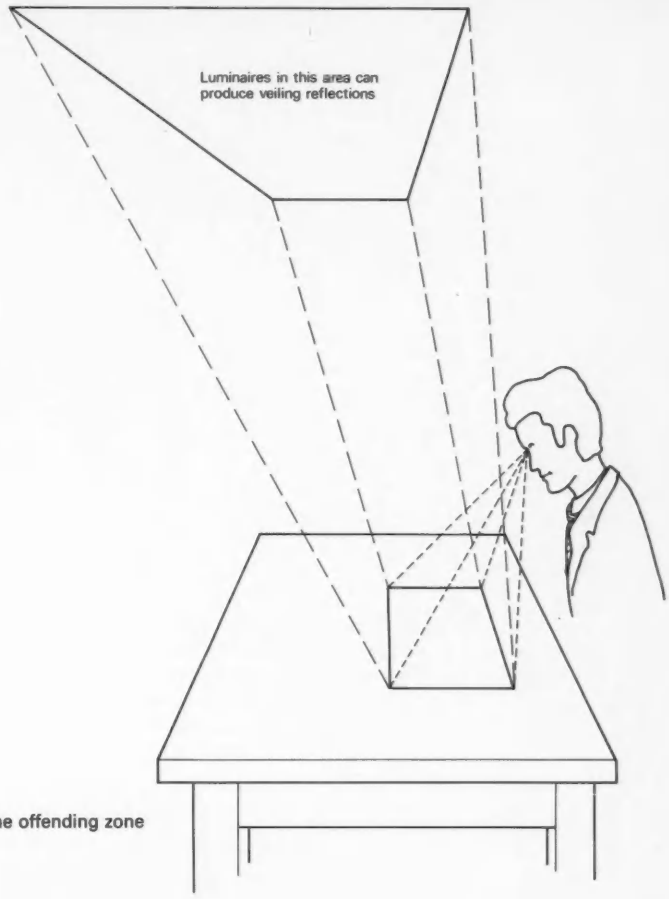

Fig 3 The offending zone

Calculation of CRF

The calculation of CRF is not easy because both direct and inter-reflected light must be considered. If the calculation is to be carried out with any reasonable degree of accuracy at a number of points within a space, a computer program is required. This is often the simplest method for determining a complete picture of the variation of CRF in an interior and the only one for installations at the design stage. A number of computer programs have been written and their predictions compared with measurements for existing installations. Some of these programs are available from commercial computer bureaux, others are used by lighting manufacturers for their own lighting designs.

Great care must be taken in the use of these programs, attention being paid particularly to the data used for the calculations. To calculate CRF it is necessary to have a very detailed knowledge of the reflection properties of the task as well as a complete picture of the direction and intensity of all the light incident on the task. These have been measured for a very few tasks and the method of measurement used is important. Calculations are therefore usually done for one of these known tasks and it is important to consider which task should be used.

The calculational complexity required to obtain accurate results means that the computer programs are all relatively large, often need considerable computation time, and so are expensive. They can, however, provide considerable detailed information, which is useful for comparing different lighting installations, especially at the design stage. They can also take into account changes in decor, eg room surface reflectances and furniture re-arangements.

Field measurement of CRF

The most fundamental visual method of measurement of CRF is with a visibility meter. This is only satisfactory for specialised research work and even then presents considerable problems. The use of a telephotometer to measure the luminance contrasts of a visual task is considerably easier and may be justified in some cases, although the equipment required is expensive and has to be handled carefully.

An instrument has been developed in Denmark which automatically compares the luminances of standard black and white tiles at a given viewing angle under a particular lighting condition and electronically computes the CRF. It is generally available, although rather expensive, and provides a very simple method of measuring CRF.

All the instruments mentioned are of a specialised nature and might be regarded as prohibitively expensive. However, a high correlation between CRF and a pair of measurements using a simple illuminance meter has been obtained*. Since CRF is strongly dependent on the proportion of the light incident on the task which comes from the offending zone, this method uses an illuminance meter tilted at 25° to the horizontal with a shield over the photocell so that only light within a cone 15° each side of the specular angle is measured. The ratio of the difference between this measurement of the light from the offending zone and the horizontal illuminance to the horizontal illuminance on the task was used to form regression equations for predicting CRF for pencil, pen and dry transfer tasks. These values were shown to correlate well with the CRF measured with a telephotometer. This simple measurement of illuminances will be of sufficient accuracy for many cases, and would certainly differentiate between positions with high and low CRF.

Design for high CRF

Whilst CRF is determined by a number of variables, some general guidelines for good CRF design can be drawn and are discussed in sequence moving away from the visual task, rather than in order of importance.

Visual tasks

Low CRF is caused by specular reflection in the task. If all visual tasks were completely matt, these reflections would not occur and the visual task contrast would remain the same irrespective of the incident light direction, giving a CRF of unity in all cases. Visual tasks which approach this ideal are available, eg matt printing on matt paper, and some types of photo-copying: their use should be encouraged.

Luminaire position

In most offices it is not possible to use only matt visual tasks and so care must be taken to avoid relatively high luminances in the offending zone (usually created by the presence of luminaires within it). This can be accomplished by the use of a luminous ceiling but these are relatively inefficient and can have other drawbacks: for example the appearance is not always suitable.

In some situations it is possible to arrange for a particular viewing direction to be used. The use of ceiling-mounted luminaires in rows parallel to the direction of view will produce high CRF values for all positions and viewing angles between the rows: only positions directly under each row will have low CRF. It is, therefore, desirable to separate the rows as much as possible since this gives larger working areas where high CRF values occur. A luminaire with a wide light output

*BOYCE P R. The Contrast Rendering Factor & Office Lighting. ECRC/R1133, Electricity Council Research Centre (1978).

distribution (such as a bat-wing distribution) is particularly useful in this case since it allows a wider separation of rows than has been common in the past.

One advantage of using rows of luminaires is that there are easily identifiable areas where will be no luminaire in the offending zone for defined viewing directions. This advantage is reduced if the luminaires are arranged in other ways, for example a chequer-board pattern.

If daylight from side windows can be used, desks should be positioned at right angles to the windows for high CRF values. In an installation using both daylight and artificial lighting, the luminaire rows should therefore be parallel to the window wall.

In many cases the direction of view cannot be controlled. If the working positions and directions of view are known, the positioning of luminaires can avoid the offending zone. If, as is more often the case, working positions are unknown, the luminaires should be arranged on the ceiling leaving as many large areas as possible without luminaires, so that these areas will be low luminance offending zones. Care must then be taken to avoid a luminaire in the offending zone when arranging the working position.

An alternative to using general ceiling-mounted lighting is to use local lighting. Luminaires should not be placed at the back of the desk but at the sides. This ensures they will usually be outside the offending zone.

Luminaire characteristics

Luminaire size A bright luminaire in the offending zone gives a low CRF; however, if the luminaire is small but with higher luminance (with, for example, high-pressure mercury or metal halide lamp), bigger areas of ceiling can be left clear than if larger fluorescent luminaires are used. This can allow more flexibility in working positions and give larger areas of high CRF, although they have to be balanced against the decrease in CRF at the fewer bad positions as the luminaire size is decreased (and the luminance increased).

Number of luminaires An alternative way of reducing the ceiling area occupied by bright luminaires is to reduce the number of luminaires used. For a given design illuminance, fewer luminaires will be required if both lamps and luminaires are as efficient as possible. An efficient lamp of suitable colour properties should be used together with an efficient luminaire, not only to reduce costs and energy consumption, but also to help to give high CRF. A wide light output distribution will also allow luminaires to be spaced at greater distances, leaving larger areas of ceiling and so increasing the number of places where working positions may be sited without a bright luminaire appearing in the offending zone.

Light output distribution This is of secondary importance to task position relative to luminaire and task specularity but a number of points do need to be considered. Polarising luminaires do not produce any great improvement in CRF and are generally less efficient. Different light output distributions usually produce improvements at some positions with disadvantages at others but bat-wing distributions allow wider spacing of luminaires. In most cases the choice of luminaire is likely to be more influenced by its utilisation factor and the discomfort glare it produces than by its effect on CRF.

Room surfaces

Since the CRF is affected by the proportion of light incident on the task from within the offending zone, it may be possible to increase the proportion of light from outside the offending zone and so raise the CRF. This can be done simply by increasing the reflectances of the room surfaces. If there is a luminaire in the offending zone the CRF will still be low but with high room surface reflectances the CRF may be raised to a more acceptable value.

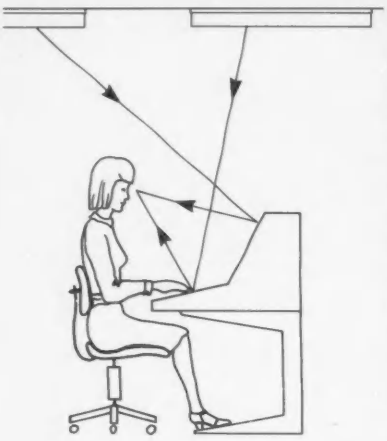

Fig 4 Prediction of veiling reflections.

Visual display units

So far, discussion has been concerned mainly with flat, horizontal visual tasks. A rather different type of task which is becoming increasingly common in offices is the VDU, consisting usually of a near vertical screen and a typewriter keyboard. Reflections in either the screen or the keys can cause problems (see Fig 4).

Reflections in the horizontal keys can be avoided by using the design methods outlined above and problems are less likely if the keys have a matt finish and are easily cleaned so that the greasy specular film that builds up can be readily removed.

Veiling reflections in the screen can both reduce the contrast (and the visibility of the display) and be distracting if they occur outside the immediate task area. These reflections can be avoided either by eliminating high luminances (usually caused by luminaires or windows) from the room or ensuring that any high luminances are not reflected towards the operator. Bright reflections of luminaires can be avoided either by eliminating the luminaires altogether and using indirect lighting or using low luminance luminaires with a narrow downward light distribution and a maximum cut-off angle of 55° from the downward vertical, such as that provided by matt black or specular louvres. Alternatively the VDU may be positioned so that bright luminaires are not reflected towards the operator. In practice this is often not easy because the screens of many VDUs are curved and a wide range of viewing angles can be used. Best results should be obtained if the VDU is placed so that the operator's line of sight is parallel to the luminaires and to the windows.

Bright reflections of windows can be avoided by using blinds or curtains. Venetian blinds or louvres are less effective than roller blinds because, when partially open, the slats and louvres can reflect a distracting striped pattern on the screen.

There is no single, simple solution that can be applied to all interiors to eliminate veiling reflections, ie to give high CRF's. The activity to be carried out will have a strong influence. Conflicts may occur between CRF requirements and those, for example, for glare or energy consumption. However, the avoidance of veiling reflections must be considered in all interiors where detailed visual tasks are performed. The final lighting design will be a balance of all the individual requirements tailored to the particular application.

Further reading

BOYCE P R & SLATER A I. The Application of CRF to Office Lighting Design. Lighting Research & Technology *13*(3) 65–69 (1981).
IES Code for Interior Lighting 1977. Illuminating Engineering Society, London. (Now Lighting Division, Chartered Institution of Building Services).
Technical Memorandum 6: Lighting for Visual Display Units, Chartered Inst Building Services, London 1981.
IES Lighting Handbook 1981. Illuminating Engineering Soc of North America.
An Analytic Model for Describing the Influence of Lighting Parameters upon Visual Performance Publication 19/2 of Commission Internationale de L'Eclairage, Paris (1981).
BRE Digest 226 Thermal, visual and acoustic requirements in buildings
BRE Digest 232 Energy conservation in artificial lighting

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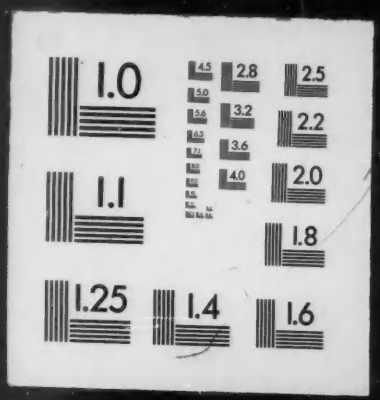
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